Proliferation Resistance Assessment of the DUPIC Fabrication Using the Revised INPRO Methodology

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1. Introduction

The IAEA initiated an International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) in 2000 for fulfilling the energy needs in the 21st century along with its economics, sustainability and the environment, safety of nuclear installations, waste management, and proliferation resistance [1]. The INPRO Phase 1B 1st part was completed with 6 national case studies and 8 individual case studies to evaluate whether or not the INPRO methodology is appropriate for the application to an innovative nuclear energy system. From the results of those case studies, the INPRO methodology was updated with 2 Basic Principles (BP), 5 User Requirements (UR) on the proliferation resistance (PR) area [2].

According to the objectives of INPRO Phase 1B 2nd part which was launched at the beginning of 2005, Korea has started the extended INPRO case study regarding to the whole DUPIC fuel cycle which covers the uranium mining and milling to the permanent disposal of the spent DUPIC fuel.

From the present study, the revised INPRO methodology in INPRO Phase 1B report was reviewed and new Indicators of the URs for BP-1 were suggested to properly assess the PR barriers. Also, the PR characteristics of DUPIC fabrication [3] by new Indicators were assessed with five-point qualitative scales such as unacceptable (U), weak (W), moderate (M), strong (S) and very strong (V).

2. Revised INPRO Methodology

The INPRO Phase 1B report [2] contains two BPs and five URs for achieving PR in an innovative nuclear energy system (INS). The BPs and URs are intended to provide guidance to governments, sponsors, designers, regulators, investors and other users of a nuclear power and the fuel cycle facilities, which incorporate the PR of the future nuclear energy system. The BP-1 has three URs and one Indicator for each UR. And the BP-2 has two URs and two Indicators for each UR. Under each indicator for URs of BP-1, there are several variables such as extrinsic measures and intrinsic features.

Meanwhile, the Indicators for UR-1, -2, and -3 of BP-1 are the same wording as URs and there is only one Indicator for each UR in the INPRO Phase 1B report. Deleting and modifying the Indicators of the revised INPRO methodology, five Indicators for the extrinsic measures of UR-1, five Indicators for UR-2 and five Indicators for UR-3 are proposed as shown in Fig. 1. But, the Indicators under BP-2 are not modified because those are reasonably described to evaluate the PR in an INS.

3. PR Evaluation of DUPIC Fabrication

In order to evaluate the PR characteristics of DUPIC fabrication using the revised INPRO methodology, the material flow was calculated based on the assumption of 10 GWe-year scale of DUPIC fuel cycle. The plutonium isotopes and radiation fields in the DUPIC fuel cycle are summarized in Tables 1 and 2, respectively.

The PR characteristics of UR-1 are dependent on not the nuclear energy system but State because Indicators of UR-1 are the extrinsic measures and the results were detailed in reference [4]. UR-2 and UR-3 are "Attractiveness of nuclear material in an INS for a nuclear weapons program" and "Difficulty and detectability of diversion of nuclear material", respectively. The assessment results for UR-2 and UR-3 are shown in Tables 3 and 4, respectively.

Since the weight fractions of ^{239}Pu, ^{238}Pu and (^{240}Pu+^{242}Pu) to total amount of Pu for the DUPIC fabrication process are 59.9 wt%, 1.7 wt% and 29.9 wt%, respectively as shown in Table 1, those evaluation parameters get the score "Very Strong", "Moderate", and "Strong", respectively, as shown in Table 3. And, the chemical form of the DUPIC fuel is oxide and the radiation field of the DUPIC fuel is 15 rem/hr as shown in Table 2. Hence, the score of those parameters are "Strong" and "Moderate".

The DUPIC fabrication process employs only the thermal and mechanical processes and there is no chemical process. Therefore, it is difficult to modify the DUPIC fuel cycle facility and processes to produce the undeclared materials. The score of the 1st Indicator in Table 4 is "Strong". The DUPIC fuel is directly re-fabricated from the highly radioactive PWR spent fuel in a heavily shielded enclosure and therefore, access to the sensitive material is extremely difficult because of the high radiation field. Hence, the 2nd Indicator in Table 4 gets the score "Strong". For the 3rd Indicator related to "Bulk/Mass", one Significant Quantity (SQ) of Pu for DUPIC fuel is main importance and calculated as 1,026 kgHM. It makes the score of the 3rd Indicator "Very Strong". The MUF (Material Unaccounted For) was calculated as 4.01 kgPu with the assumption of 10

GWe/year scale of the DUPIC process and its score is "Moderate". Since there is no chemical process in DUPIC fabrication, the score of "Skills, expertise and knowledge …" of the last Indicator in Table 4 is "Strong".

4. Conclusion

The INPRO methodology in Phase 1B report provides a reasonably well framework for the overall evaluation of an innovative nuclear system in the PR area except the minor modification of the Indicators.

The present study proposed several Indicators for UR-1, -2 and -3 of BP-1 to properly assess the PR of an INS. And the PR characteristics of DUPIC fabrication with the assumption of 10 GWe-year scales are evaluated for UR-2 and -3 of BP-1.

However, it is needed further development of the quantification of Indicators and significance among Indicators to evaluate URs because the evaluation of UR is required to integrate the Indicators.

Acknowledgements

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Table 1. Plutonium Isotopes in DUPIC Fuel Cycle

Isotopes	PWR SF		Fresh DUPIC Fuel		DUPIC SF	
	g/MtHM	wt% of Pu	g/MtHM	wt% of Pu	g/MtHM	wt% of Pu
PU238	1.54E+02	1.7	1.54E+02	1.7	3.88E+02	4.9
PU239	5.33E+03	59.9	5.33E+03	59.9	3.16E+03	39.7
PU240	2.20E+03	24.8	2.20E+03	24.8	2.79E+03	35.1
PU241	7.52E+02	8.4	7.52E+02	8.4	5.24E+02	6.6
PU242	4.57E+02	5.1	4.57E+02	5.1	1.10E+03	13.8

Table 2. Radiation Field in DUPIC Fuel Cycle

Items		Dose rate (rem/hr) for diversion of one assembly or one bundle	Total dose rate (rem/hr) for 1000kgHM diversion	Dose rate (rem/hr) for diversion of 1 SQ(8 kg Pu)
PWR SF	35GWD/MTU, 10yrs cooling	1,037	2,356	2,121
DUPIC SF	15GWD/MTU, 10yrs cooling	61	3,216	3,232
CANDU SF	7.5GWD/MTU, 10yrs cooling	22	1,151	2,284
Fresh DUPIC	PWR(35GWD/MTU, 10yrs cooling)	15	797	717

Table 3. PR Assessment Results of UR-2 of BP-1

Indicators	Evaluation Parameter	Evaluation scale				
		U	W	M	S	V
IPR1.2.1: Isotope content	239Pu/Pu (wt%)	> 93	80~93	70~80	60~70	< 60
	235U/U (wt%)	> 90	50~90	20~50	5~20	< 5
	232Ucontam. for 233U (ppm)	< 1	1~100	100~4000	4000~7000	> 7000
IPR1.2.2: Chemical form	Chemical form	Pure Pu metal	PuO_2, PuN	Fresh MOX	Spent fuel	Spent fuel with high burnup
IPR1.2.3: Radiation field	Dose (rem/hr)	< 1	1~15	15~100	100~1000	> 1000
IPR1.2.4: Heat generation	238Pu/Pu (wt%)	< 0.1	0.1~1	1~10	10~80	> 80
IPR1.2.5: Spontaneous neutron generation rate	(240Pu+ 242Pu) /Pu (wt%)	< 1	1~10	10~20	20~50	> 50

Table 4. PR Assessment Results of UR 3 of BP-1

Indicators	Evaluation Parameter	Evaluation scale				
		U	W	M	S	V
IPR1.3.1: Difficulty to modify fuel cycle facilities and process for undeclared production	Degree of difficulty	Very easy	Easy	Medium	Difficult	Very difficult
IPR1.3.2: Design features that limit access to NM	Environment between proliferator and NM	Open	Limited open	Glove box, concrete, or metal	Shielded hot cell	Geological media
IPR1.3.3: Bulk/Mass	Mass (kg)	< 10	10~100	100~500	500~1000	> 1000
	Size (cm)	< 10	10~40	40~100	100~300	> 300
IPR1.3.4: Diversion detectability (MUF)	Kg Pu or 233U	> 16	8~16	4~8	2~4	< 2
	Kg 235U with LEU	> 50	25~50	25~12	7~6	< 6
	Kg 235U with HEU	> 150	37~75	18~37	9~18	< 9
	Ton Th	> 40	20~40	10~20	5~10	< 5
IPR1.3.5: Skills, expertise and knowledge required to divert or produce NM and convert it to weapons useable form	Degree of skills, expertise and knowledge	Very high	High	Medium	Low	Very low

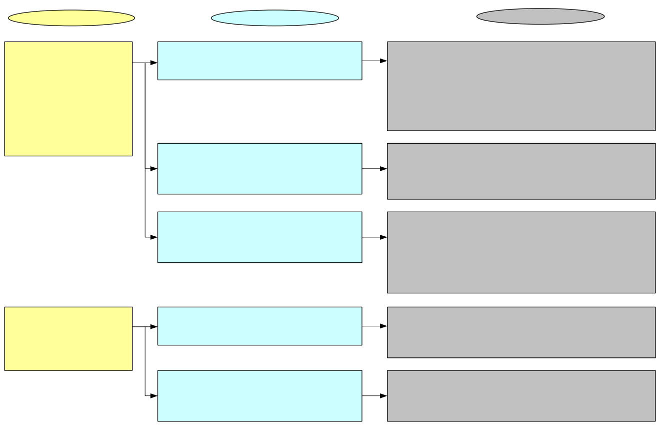

Figure 1. Proposed Indicators for UR-1, -2 and -3 of BP-1